Population Consequences of Acoustic Disturbance of Marine Mammals

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LONG-TERM GOALS

The long-term goal of this project is to improve understanding of the effects of sound and other anthropogenic and natural disturbances on probabilities of population-level or species-level persistence of marine mammals. Disturbances can lead to alterations in physiological or behavioral states of animals, which in turn may lead to changes in demographic rates and viability. Population-level effects of disturbance also may cascade among species. However, it has proven difficult to identify and model the mechanisms by which individual-level responses might propagate to the population level. A clear and ideally quantitative understanding of such mechanisms is necessary to assess trade-offs between potential responses of species to disturbance and diverse human activities.

OBJECTIVES

1. Explore how the U.S. National Research Council (NRC) committee's 2005 conceptual model of population-level effects of changes in behavior of marine mammals might be translated into quantitative models.

2. Consider how the NRC committee's conceptual model might be parameterized with existing or emerging data on the responses of large vertebrates to disturbance.

3. Define conceptual approaches for investigating transfer functions (e.g., time-energy budgets, trait-mediated responses).

4. Expand work by the NRC to include sensitivity analyses of different transfer functions.

5. Outline exploratory models that might be used to model transfer functions, synthesize existing knowledge, examine potential mechanisms, or inform research and management.

APPROACH

Work is conducted by a multidisciplinary research team of approximately 15 core participants with oversight from a steering committee [Dan Costa (University of California, Santa Cruz), Erica Fleishman, John Harwood (University of St. Andrews), Scott Kraus (New England Aquarium), and Mike Weise (Office of Naval Research)]. Peter Tyack (University of St. Andrews, formerly Woods

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Hole Oceanographic Institution) served on the steering committee through June 2012. Kraus joined the steering committee in July 2012. Additional participants contribute to some aspects of the project. The team meets in person approximately every six months to iteratively develop and interpret models and refine deliverables. Participants conduct the majority of analyses and writing at their home institutions between meetings.

During the report fiscal year, core participants were Jim Clark (Duke University), Dan Costa, John Harwood, Mark Hindell (University of Tasmania), Scott Kraus, David Lusseau (University of Aberdeen), Clive McMahon (Charles Darwin University), Dave Moretti (Naval Undersea Warfare Center), Leslie New (United States Geological Survey, formerly University of St. Andrews and Marine Mammal Commission), Rob Schick (Duke University), Lisa Schwarz (University of California, Santa Cruz), Sam Simmons (Marine Mammal Commission), Len Thomas (University of St. Andrews), and Peter Tyack.

WORK COMPLETED

The project team has convened five times: 28 September–1 October 2009 and 4–6 March 2010 in Santa Barbara, California, 7–9 September 2010 in Woods Hole, Massachusetts, 10–12 April 2011 at the Atlantic Undersea Test and Evaluation Center (AUTEC), and 22–24 October 2011 in Washington, D.C. During the first meeting, the group developed a model for analyzing energy change during foraging trips by northern and southern elephant seals (*Mirounga angustirostris* and *M. leonina*, respectively) and the effects of this energy change on pup survival. During the second meeting, the group began to develop a model for coastal populations of bottlenose dolphins (*Tursiops* spp.). The third meeting focused on how disturbance might affect northern right whales (*Eubalaena glacialis*). During the fourth meeting, the group developed a model for Blainville's beaked whales (*Mesoplodon densirostris*) on the AUTEC range. During the fifth meeting, the group reviewed progress to date and discussed objectives and logistics for the next phase work.

On 21 October 2011, a subset of the project team participated in a symposium in Washington, D.C. that was cosponsored by ONR and the Marine Mammal Commission. Nine presentations introduced the audience to project objectives, methods, preliminary results, and potential applications to decision-making and management.

Fleishman and Thomas delivered presentations based all or in part on the project at the Biennial Conference on the Biology of Marine Mammals in Tampa, Florida, in December 2011. Harwood presented project research at a workshop on effects of marine anthropogenic sound in Bristol, United Kingdom, in February 2012 and a workshop on managing risk to marine mammals from marine renewables devices in Edinburgh, United Kingdom, in March 2012.

Elephant seals
Schwarz is defining the functional relation between maternal health and pup survival in southern elephant seals. As of July 2012, she had detected a positive although highly variable relation between maternal lipid mass and pup wean mass. Pup separation, whether a female previously reproduced, and crowding may reduce the strength of the relation. The relation between pup wean mass and pup survival was quadratic, and pups with a wean mass near 160 kg had the highest probability of surviving their first year. The relation between maternal lipid mass and pup survival was not particularly strong, although pup survival increased slightly as maternal lipid mass increased from about 120 to 180 kg. Schwarz also is investigating the functional relation between health and survival,

and between health and reproductive rate, in northern elephant seals. Because the length of a foraging trip is related to whether a female is pregnant, Schwarz examined reproductive rate as a function of lipid-gain rate. Preliminary results suggest there may be a correlation between the percentage of lipid mass and the probability of survival; no female has been measured with a lipid mass lower than 27%.

Coastal populations of bottlenose dolphins
Researchers began collecting data on bottlenose dolphins in Sarasota Bay, Florida in 1970. Eight databases contain information that may inform models of population-level effects of disturbance: sightings (mark-recapture), female reproductive history, body condition and morphometrics, strandings, health, fish survey, behavioral follows, and acoustics. Two databases, health and body condition and morphometrics, contain the data collected during capture-release health assessments. In July 2012, Schwarz participated in health assessments in order to understand the assessment process and begin exploring how the data may be used to estimate population-level effects of disturbance.

Northern right whales
Schick is quantifying changes in health of individual right whales over time and space and assess the relation between health and survival. A Bayesian model has been fit to all of the individuals in the population. The four outputs from the model are estimates of model parameters; estimates, with credible intervals, of individual health; individual movement; and individual survival. Typical results for an individual are health over time and effects of different stressors on that animal's health. The model allows for inference to densities of right whales in different geographic regions and probable monthly transitions among those regions.

Beaked whales
Moretti is estimating the population-level effects of sonar on Blainville's beaked whales in the Bahamas. He is predicting the probability of dive disruption at a given level of exposure to sonar. Groups of vocalizing animals on the AUTEC range were isolated with detection archives from other Navy projects. Data were divided into 30-min periods. The maximum exposure within each period was obtained for each hydrophone on the range at each of five depths.

M. densirostris vocalizations were isolated on all hydrophones. Click trains were identified and associated with a single Group Vocal Period (GVP). The total number of GVP starts within a time period was calculated for each hydrophone. A generalized additive model was used to fit the GVP start as a function of RMS on the center hydrophone for each 30-min period at each of the six depths. Moretti calculated the baseline probability of a GVP start (P_B, no sonar) and the probability of a change in the baseline probability, or the probability of disturbance (P_C). The probability of disturbance given the sonar levels received at 100 m was compared to the historic Navy risk function. A generalized linear model with a sigmoidal (probit) link function was used to fit the measured risk function. This provided a mathematical expression that can be applied to levels of exposure from ambient to high.

RESULTS

It may be prudent for studies that place non-permanent marks on animals to place at least two different types of marks on at least a subset of animals. Estimation of survival and reproductive rates of many organisms requires following identified individuals through time. Survival rates are underestimated when marks are lost because models will effectively score those individuals as dead. To account for mark loss, some researchers use double marks, assuming that the probability of losing

each type of mark is independent. Therefore, mark loss can be estimated from animals that have lost one mark. Schwarz et al. found that the assumption of independent tag loss in southern elephant seals was not valid. It was more likely for an animal to lose both tags than one tag. The assumption of independent tag loss leads to underestimation of survival rates, which in turn leads to underestimation of population growth rates. In addition, tag loss rates differed by sex, age, and wean mass through age two, possibly due to differences in behavior, flipper growth, and immune response.

Foraging location significantly affected lipid gain in elephant seals, and ultimately might affect probability of persistence. Foraging success can affect behavior, movement, and fecundity. Elephant seals make drift dives during which they do not feed or swim but are thought to be processing food. Their vertical ascent or descent rate during these dives is a proxy for buoyancy and thus body condition. Schick et al. generated continuous estimates of lipid gain and loss of northern and southern elephant seals during 8 months of foraging at sea on the basis of observed buoyancy. They tested whether foraging location affects lipid gain, condition when the animal departs from the colony affects lipid gain, environmental covariates affect lipid gain, and animals gain lipids at different rates during various phases of the trip. A hierarchical Bayesian state-space model estimated daily lipid gain and loss of elephant seals. In the underlying process model, lipid gain was a function of environmental covariates. An observation model linked the hidden states in the process to observed data on median daily drift rate. Markov Chain Monte Carlo was used to fit the model to data for each species. The project team found that foraging location significantly affected lipid gain in both species, especially southern elephant seals.

A group led by New modeled the energetic requirements of adult female beaked whales for survival and reproduction. Stochasticity was entered into the model through individual-level variation, uncertainty around parameter values, and variation in daily energy consumption by individual whales. Estimates of accessible energy, maternal length, calf length at birth, calf length at weaning, type of prey, energetic content of prey, gestation time, length of lactation, and group size were derived from the literature. Simulations were run for each of the 21 species of beaked whales. Simulation results indicated low rates of survival and reproduction for five of the 21 species. These species tended either to feed on prey with a low average energetic content or to have relatively large maternal size and a restricted lactation period. The remaining 16 species had different rates of survival and reproduction over a range of possible parameter values, which helped to assess the sensitivity of the model to differences in those values.

Given certain sets of assumptions, coastal bottlenose dolphins may not be affected by an increase in vehicle traffic. New et al. also simulated the spatial distribution, social structure, behavioral time budgets, and response to disturbance of coastal bottlenose dolphins in the Moray Firth, Scotland. First, New ran the model assuming that dolphins do not respond to current levels of human activity in the Moray Firth. Next, she used the model to project dolphins' response to a hypothetical increase in traffic from 70 to 470 vessels a year. The increase in traffic was associated with offshore production of renewable energy in part of the Moray Firth. The initial simulation model yielded biologically realistic estimates of school-size distributions, behavioral time budget, motivational states, and spatial distributions. Assuming no change in the dolphins' habitat other than an increase in vessel traffic (e.g., no increase in sound from the vessels or the energy-production facility), and that behavior is affected only by the presence of vessels, New found no change in response variables following an increase in vessel traffic. This result may reflect that even with an increase in traffic, commercial vessels typically are present for no more than a few minutes a day in a given grid cell. Thus, the probability that a school will encounter a boat in a given cell remains small.

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APPLICATIONS

Multiple public and private sectors wish to understand whether observed changes in animals' behavior or physiology affect probabilities of persistence. Subsistence hunters also wish to understand whether short-term changes in behavior may affect long-term spatial distributions of animals. The concept that behavioral responses to disturbance are not necessarily surrogate measures of population-level responses is widely understood. However, without tractable methods for quantifying population-level effects, most sectors will be restricted to estimating exposure of individual animals to disturbances, changes in habitat quantity or quality, and behavioral responses of individual animals. Thus, improved understanding of transfer functions might help to guide research and management, and to project how marine mammals will respond to alternative scenarios of human activities, from those that produce sound to climate change to changes in human density and distributions. Deliverables and inferences from the team's work, and direct communication with potential end-users, may inform national and international legislation and scientific guidance on managing marine mammals. Examples include the Endangered Species Act and the Marine Mammal Protection Act in the United States, the IUCN Red List categories and criteria, and the Species and Habitats Directive in the European Union.

RELATED PROJECTS

Fleishman is leading a project on cumulative effects of underwater anthropogenic sound on marine mammals for BP Exploration. To date, the cumulative-effects project has focused on effects at the individual level. The ONR-sponsored project may provide a means for evaluating how effects might transfer to the population level.

In April, 2012, ONR funded a second phase of the working group's collaboration. This work will be based on four major activities. First, participants will either complete models initiated during the first phase of the project or expand on previous work to increase its generality. Second, the group will prioritize data collection to estimate population-level effects of different classes of disturbance on marine mammals with different life-history attributes. Third, the team will examine the inferences about effects of disturbance on individuals and populations that can be drawn on the basis of limited empirical information. Fourth, the group will compare inferences about population-level effects of disturbance that are based on extensive empirical data to those based on expert elicitation (e.g., Martin et al. 2012, McBride et al. 2012).

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